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Hands-on, Minds-on Periodic Table: Visualizing the Unseen
(Middle School Version)

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National Science Content Standards:
Standard A: (Scientific Inquiry) *- develop abilities necessary to do scientific inquiry; understandings about scientific inquiry*
Standard B: (Physical Science) *– understanding of properties and changes of properties of matter*

National Science Teaching Standards:
Teaching Standard A**:** Teachers of science plan an inquiry-based program for their students. In doing this, teachers

- Select science content, adapt and design curricula to meet the interests, knowledge, understanding, abilities, and experiences of students.
- Select teaching and assessment strategies that support the development of student understanding, and nurture a community of science learners.

Teaching Standard B**:** Teachers of science guide and facilitate learning. In doing this, teachers

- Focus and support inquiries while interacting with students.
- Orchestrate discourse among students about scientific ideas.

Teaching Standard C**:** Teachers of science engage in ongoing assessment of their teaching, and of student learning. In doing this, teachers

- Use multiple methods and systematically gather data about student understanding and ability.
- Guide students in self-assessment.

Teaching Standard E**:** Teachers of science develop communities of science learners that reflect the intellectual rigor of scientific inquiry, the attitudes, and social values conducive to science learning. In doing this, teachers

- Nurture collaboration among students.

California Science Content Standards:

3. Each of the more than 100 elements of matter has distinct properties and a distinct atomic structure. All forms of matter are composed of one or more of the elements.

3a. Students know the structure of the atom and know it is composed of protons, neutrons, and electrons.

3b. Students know that compounds are formed by combining two or more different elements and that compounds have properties that are different from their constituent elements.

3c. Students know atoms and molecules form solids by building up repeating patterns such as the crystal structure of NaCl or long-chain polymers.

3f. Students know how to use the periodic table to identify elements in simple compounds.

5. Chemical reactions are processes in which atoms are rearranged into different combinations of molecules.

5a. Students know reactant atoms and molecules interact to form products with different chemical properties.

7. The organization of the periodic table is based on the properties of the elements and reflects the structure of atoms.

7a. Students know how to identify regions corresponding to metals, nonmetals, and inert gases.

7b. Students know each element has a specific number of protons in the nucleus (the atomic number) and each isotope of the element has a different but specific number of neutrons in the nucleus.

9. Scientific progress is made by asking meaningful questions and conducting careful investigations.

9a. Students will plan and conduct a scientific investigation to test a hypothesis.

9b. Students will evaluate the accuracy and reproducibility of data.

9c. Students will distinguish between variable and controlled parameters in a test.

Note: Please read through lesson plan before purchasing materials.

Materials:

- 4 (s-, p-, d-, f-) blocks of the periodic table, laminated (computer files available at http://www.csupomona.edu/~ceemast/science/scienceLessonPlans.htm *OR www.rialtoschools.org – navigation directions in lesson plan*
- 132 1.5" Styrofoam balls
- 5/8" Velcro dots (sticky back), one for each Styrofoam ball
- glue suitable for plastic (Styrofoam glue recommended)
- 10 different acrylic colors, 1 choice being a metal color (preferably silver)
- Chenille stems (pipe cleaners): 2 different colors (66 12" stems of color 1; 100 12" stems of color 2, each cut into quarters)
- One 6" Styrofoam ball cut in half
- Two pkgs. beads of 2 different colors (one of each)
- Beading wire or thread and small needle (for stringing beads)
- 1 pkg. multicolor quilting pins

- 1 class set of individual illustrated periodic charts, laminated (Periodic Table of the Elements (11 x 18 inches), 100 pk available at http://www.acs.org) – *navigation directions in lesson plan*
- Chart paper and markers
- Bags of assorted buttons – enough for each student group (see *Final Assessment* in lesson 4)

Pre-lesson preparation:

Large Periodic Table:
You will need to print (or make by hand) a very large periodic table whose boxes are 5-6 inches square. Each block of the periodic table [s (left two columns), p (right hand 6 columns), d (10 columns across the middle), and f (14 columns at the bottom)] is on a separate sheet of paper. Each square contains the elemental number, but no other information. We used butcher paper and then laminated the separate parts. Once laminated, you can write on them with water soluble markers. Computer files of the large Periodic Table "skeleton" are available at http://www.csupomona.edu/~ceemast/science/lessons OR www.rialtoschools.org *[Navigation directions: click "Group Pages" → click "Curriculum & Technology" → click "Elementary Math & Science" → click "SMART 5th grade Science Training" folder]*

Painting the Atoms (Styrofoam balls):
Styrofoam balls are used to represent atoms. The different atoms belonging in each column of the s- and p-blocks (main group elements) are painted a different color. For the d-block, silver balls are used for each atom regardless of "family" (column or number of electrons). You will need a total of 10 colors; unpainted white works for one of the choices (we used white unpainted balls to represent the noble gases). See Table 1 for the numbers of Styrofoam balls of each color needed. Extra column 1 & column 7 balls are recommended for use in making binary compounds in lesson 1 and lesson 4.

Table 1: Numbers of Styrofoam Balls of Each Color

Number of Balls Needed	Color	*Column #* *(# of Valence e-)*	*Block*
22	1	1	s
6	2	2	s
6	3	3	p
6	4	4	p
6	5	5	p
6	6	6	p
21	7	7	p
6	8*	8	p
1	9*	8 (2 valence e-)	s
40 (metal color)	10	3B – 12B (see table 2)	d

*We suggest that color 9 be a variation of color 8 (e.g. a lighter shade of the same color). The one “atom” that is painted color 9 represents He, a noble gas; the atoms painted with color 8 will also be noble gases.
(Note: Styrofoam balls are not very durable if you they are extensively used. Ping pong balls are a durable alternative – simply drill 1/32” holes in the ping pong balls with a Dremmel tool *or* use a push pin to accommodate the chenille stems).

Adding the Outer (Valence) Electrons to Atoms:
Each “atom” has its valence electrons explicitly displayed by placing chenille stems into Styrofoam balls and bending the ends into hooks (the purpose of creating hooks is to allow attachment to other atoms’ hooks, thus doing “chemistry”). *Management tip:* We used one color of chenille stems for unpaired electrons and another color for the paired electrons to enable teacher spot-check of student work quickly. Point out to students that all valence electrons are the same even though they are represented by 2 different colors.

The H and He atoms have only one “house” (orbital) to hold electrons; the two electrons of He are paired. The rest of the atoms in the s- and p-blocks have four electron “houses” (orbitals); the atoms with 5 electrons have 1 pair of electrons and three that are unpaired. Be sure to twist the hooks of paired electrons together so they cannot do any “chemistry.” Because electrons are all negative in charge, they are as far away from each other as possible. Geometries of each type of atom in these blocks are illustrated in Figure 1. [For more information about the geometries adopted by the electrons in these orbitals, please see an introductory chemistry text such as Atkins and Jones, Valence Shell Electron Pair Repulsion (VSEPR) discussion.] The atoms belonging to the d-block have six electron “houses” (orbitals); the atoms with 7 electrons have 1 pair of electrons and 5 unpaired electrons. See Figure 2 for illustrations of each geometry for the atoms in this set of “atoms” are available at:
www.chemistry.wustl.edu/~edudev/vseprtable.pdf or
www.shef.ac.uk/chemistry/vsepr/jmol/geometries.html

Table 2 informs you how many chenille stems are needed for each atom.

Table 2: Number of Chenille Stems For Each Styrofoam Ball

Number of Balls	Paint Color	# Chenille Stem Color 1[a]	# Chenille Stem Color 2 [b]	Angle[c]	Geometry[d]
Main Group (s- and p-block) Elements					
22	1	1	0		
6	2	2	0	180°	linear
6	3	3	0	120°	trigonal planar
6	4	4	0	109.5°	tetrahedral
6	5	3	2	109.5°	tetrahedral
6	6	2	4	109.5°	tetrahedral
21	7	1	6	109.5°	tetrahedral
6	8*	0	8	109.5°	tetrahedral
1	9*	0	2		

Transition Metals (d-block) Elements					
4	10	3	0	120°	trigonal planar
4	10	4	0	109.5°	tetrahedral
4	10	5	0	two at 180°; three on "equator" at 120°	trigonal bipyramid
4	10	6	0	90°	octahedral
4	10	5	2	90°	octahedral
4	10	4	4	90°	octahedral
4	10	3	6	90°	octahedral
4	10	2	8	90°	octahedral
4	10	1	10	90°	octahedral
4	10	0	12	90°	octahedral

[a]Chenille stem color 1 is used to represent unpaired electrons; each occupies one "space" on the Styrofoam ball. [b]Chenille stem color 2 is used to represent paired electrons; two are used in each "space" on the Styrofoam ball. [c]It is not necessary to measure the angles exactly; "eyeballing" the angles should be sufficient. [d]These are the "base" geometries used to describe the orientation of the electrons.

Glue on the Velcro Dot:
Glue a 5/8" Velcro dot (loops) onto *each* Styrofoam ball (use glue for Styrofoam or plastic to hold them on!); the hook half (scratchy side) gets put onto the periodic table. we used sticky Velcro dots and only needed to use glue on the Styrofoam balls.

Divide the s- and p- block atoms into bags, one for each group of students. Each bag should have a variety of atoms with different numbers of valence electrons. Do the same for the d-block atoms (transition metals) making sure that each bag has an assortment of atoms with different numbers of valence electrons. You should now have two sets of bags - one with the main group atoms (all different colors) and another set with transition metal atoms of just color 10.

Atomic Nuclei:
You will also need a class set of atomic nuclei. We made C nuclei by using 2 different colors of small beads. String 6 beads of each color alternately while drawing the string or wire through beads multiple times to end up with a ball of beads. The two colors of beads represent protons and neutrons. One of the nuclei should have an "extra" bead of one color (extra neutron); this represents an "isotope" of that type of atom. (Elements are defined by the number of protons in their nuclei; isotopes are elements that have the same number of protons but a different number of neutrons in the nucleus. Isotopes are naturally occurring.)

6” Styrofoam Ball:
Cut in half the 6” Styrofoam ball. Use one half to make a cut-away model of an oxygen atom, and the other half to make another model of a different element with more inner electrons (e.g. bromine). Make two nuclei (one of oxygen and another to match your chosen second element) out of beads for these cut-away models leaving extra wire on the ends to push into the Styrofoam ball. Then add quilting pins to represent the core or inner electrons. The correct numbers of valence electrons then need to be added to the outside surface of the ball using chenille stems.

Lesson Construction:
This lesson is written as a series of questions (guided inquiry) instead of as a lecture so that students are more actively engaged in thinking during the lesson, thus constructing their own understanding. Feel free to add or modify the questions to accommodate your students’ needs. Please share additional questions with us so we can add them to subsequent revisions of this script.

We also have included embedded assessments (ongoing or formative assessments) that allow you to determine whether or not the students have gotten the idea along with helpful hints (usually in the form of a question) to help your students along in the thought process.

Lastly, we have made use of different fonts to make visible the teacher voice, explanations and background commentary for teacher and/or students, and what the teacher does. We have also placed boxes around things you might want to post or put onto an overhead.

LESSON 1: INTRODUCTION TO ATOMS AND MOLECULES

Lesson 1 Concepts:
1. Chemists use a specific form of notation to record chemical reactions.
2. Atoms combine to form molecules according to the number of valence electrons available on each atom.
3. Atomic structure: atoms are composed of protons, neutrons, and electrons.
4. The atomic number (number of protons) defines the element and isotopes.

Teacher Preparation:
- 4 periodic table blocks are laminated and hanging up in front of the classroom
- Chart paper and markers for KWL
- s- and p-block atoms are divided and in bags, one bag per group
- Questions for think-pair-share on chart paper or handout
- Laminated illustrated periodic tables for students or pairs of students to use. Available at http://www.acs.org – *[Navigation directions: choose “Natl. Chem Week” under “quick files” in left hand column of the page → click “On-line Store” → click “Search” → type “periodic table” into keyword box]*

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***Suggested Pre-lesson Activities*:**

- KWL chart on periodic table
- Introductory research on periodic table
- Text reading covering topics: atoms, elements, periodic table

Lesson begins with empty, huge periodic table on the wall. The s-block has two columns with the number 1 in the top left box, and should be placed on the left side of the wall. Next place the d-block (10 columns wide with the number 21 in the upper left box) to the right of the s-block so that the box containing 21 lines up with the box containing 20. The p-block containing 6 columns (and has the number 2 in the top right box) is then placed to the right of the d-block so that the box with 31 lines up with the box containing 30. Now place the f-block (14 columns wide with two rows) across the bottom of your periodic table.

Note: Teacher voice in this script is in Comic Sans font.

Small groups: Distribute illustrated periodic tables. Sample questions to ask students during think-pair-share:

1. What is the title of what you are seeing? (The Periodic Table of Elements)
2. What do you see on this table? (boxes, numbers, letter, etc.)
3. Do you notice any patterns? (increasing atomic #s, group #s, etc.)
4. What do the letters in the boxes represent? (elements)
5. What information do the boxes contain? (atomic number = number of protons, elemental symbol, weight = weighted average of all isotopes)
6. What do you know about elements? (Three questions above are meant to solicit prior knowledge from students. **Element** = a collection of atoms that all have the same number of protons in their nucleus – even if they do not have the same number of neutrons)
7. Do you see any familiar elements on this table?
8. What differences do you see between the different elements/boxes? (different atomic numbers, different symbols, etc.)
9. If elements are made of atoms, what are atoms made of? (**atoms**, the smallest part of matter that cannot be broken down further ***by chemistry***, are made of **protons, neutrons, and electrons**)
10. Where are the parts of the atom located? (protons and neutrons are located in the central nucleus while the electrons are on the outside of the nucleus – protons are positively charged, neutrons are neutral, and electrons are negatively charged.)

Whole group:

Share out from think-pair-share, reinforce vocabulary, any trends in periodic chart. (Teacher should note any misconceptions – refer to *CSTA "Ca. Journal of Science Education: Dealing with Science Misconceptions,"* Vol. V, Issue 2, Spring 2005, p.159 – 167). An example of misconceptions in this lesson is vocabulary.

Show students cut-away model of oxygen atom. Sample questions to ask students:

1. Can you find oxygen on the periodic table (#8)?
2. What is the symbol for oxygen? (O)
3. Where is it? (third column from right edge, second row)
4. What is the mass number? (16)
5. Where is the mass of this atom located? (in the nucleus: protons and neutrons account for 99.9% of an atom's mass, whereas the mass of electrons are negligible)
6. How many protons does it have? (8)
7. How many total electrons does it have to be neutral? (8)
8. How many neutrons does ^{16}O have? (8) How do you know? (mass number – protons = 8 neutrons)
9. Why is oxygen not exactly 16.000 in its mass? (isotopes, different numbers of neutrons)
10. If oxygen had 7 neutrons, is it still oxygen? Why? (oxygen still has 8 protons, **the atomic number therefore defines the element**)
11. What if oxygen did not have 8 protons, but had 7 protons instead? Would it still be oxygen? (no, it would be nitrogen; the number of protons defines the type of atom).
12. Can someone count the electrons in this model?
13. Do some atoms have more protons and electrons than others? (yes)
14. Are all electrons at the same distance from the nucleus? (no)

Right, we can think about the atoms as if they were onions, with sets of electrons in each onion layer.

Showing the oxygen atom model, ask students to notice the inner layer of electrons, and the outer layer of valence electrons (chenille stems). Sample questions to ask students:

1. How many outer electrons does it have (chenille stems)? (2)
2. How many inner electrons? (6)
3. How are the 6 outer electrons arranged? (2 are alone, two are pairs of electrons)

(This oxygen atom is NOT to scale – the nucleus shown here is too large for this atom, all electrons are equal regardless of position, core electrons are "hidden" inside and are not visible from the outside). The nucleus would be too small to see if the atoms were this size. A more accurate scale could be represented by a period (the nucleus) in a stadium (the entire atom).

Today's lesson will focus on the behavior of the electrons on the **outside** of the atom. These electrons are called the **valence** electrons. They are represented by hooks so they can hook-up with other atoms that also have hooks on them –this means they are doing “chemistry.” The inner electrons are already paired, so they are not available for doing chemistry.

Here is a cut-away model of another atom (6 inch Styrofoam ball cut in half with a nucleus and core electrons depicted by heads of quilting straight pins of different colors). Show it to everyone. Ask students to compare and contrast oxygen atom model to this model of another atom. Sample questions to ask students:

1. What do you notice about this model?

Ask students to compare and contrast the oxygen atom model to the model of the other atom.

2. How are they different? (different number of electrons)
3. What is similar between the two atoms? (they both have a nucleus + core electrons + valence electrons)
4. What type of atom is this? How do you know? (count the number of protons, the atomic number determines the element).

Small groups:
Distribute atoms: Bags of main group (s-,p-block) to student groups.
Each group should now have a collection of atoms on their desks. Ask students to examine the atoms in their bags.

In this model, only the valence electrons on the outside of the atoms are known. Nothing about what is inside the atom is known. (You may need to remind students of this later!)

Sample questions to ask students (note: we used yellow chenille stems for paired electrons, and green for unpaired electrons):

1. What can you say about the atoms in your bags? (yellow electrons are internally paired, green are unpaired electrons, atoms have between 1 and 8 electrons, they have different colors, they are spherical, they have Velcro dots, all balls are same size. Note that although two different colors of chenille stems are used to represent paired and unpaired electrons, all electrons are exactly the same. Note also that atoms are not all the same size, are not colored, and do not have Velcro dots on them.)
2. What do the chenille stems (pipe cleaners) represent? (valence electrons)
3. Why are the valence electrons of each atom spread away from one another? (all electrons are negative, and negative charges repel)
4. Count the valence electrons. How many? (1-8)
5. Where are the rest of the electrons? (can’t see them, they are inside the atom)

But these atoms only have 4 houses (orbitals), each of which can hold a maximum of 2 electrons.

1. So what do electrons do if an atom has 5 electrons and only 4 spaces? (2 electrons must pair up!)

2. Why are some of the valence electrons hooked together? (they are paired up, they have a partner)
3. Do you think electrons on the same atom want to be paired up? (not unless they have to, they have the same charge and like charges repel each other)
4. If the paired electrons are hooked together, can they do chemistry? (no)

Make sure all your valence electrons are connected:

1. How many pairs of electrons do you see on these atoms?
2. How many lone electrons do you see?
3. How many total electrons do you see?
4. Where are the remaining electrons of these atoms? (hidden inside)

(My model makes it appear as if there are 2 types of electrons – this is not true, all electrons are the same!)

Electron Behavior:

- The electrons want to be paired; but they only pair **internally** when forced to do so.
- Unpaired electrons (lone ones) are what we call "reactive". In order to become more stable, they need to find **external** electron partners. Atoms can no longer do chemistry when there are no more unpaired electrons – they want to look like noble gases.
- Making new electron-electron pairings is what we call **chemistry** or a **chemical reaction** to become more stable.

Working with others in your group, or multiple groups:

Ask students to make new **molecules** (chemicals that have one or more atoms bonded together) from only two types of atoms, or binary compounds (**binary compounds** = molecules with 2 different types of atoms).

Before we do any chemistry, we need to be sure we are safe (Put on goggles!) So, now we can do some chemistry and make some new **bonds** (or new electron-electron connections) between two atoms.

Rules:

- Use only two differently colored (or two types of) atoms to connect the green electrons - use as many as you need
- You are all done when all unpaired valence electrons have a single partner and none are left unpaired.

Now, go ahead and see what sorts of binary compounds your group can make.

Sample questions to ask students:

1. What combinations did you make?
2. How many of each type of atom did you have to use?
3. What atomic ratios did you find in your binary compounds?

Class share-out the types of compounds they made. Teacher charts responses (save charted responses for lesson 3):

For example, write on the board: 2 yellow + 3 green $\Rightarrow$ 2Y+3G $\Rightarrow Y_2G_3$.

This is called "expert" chemical writing. This is the shorthand way chemists use to describe chemicals/compounds/chemical formulae/combining ratios. For example: H_2O has how many hydrogen atoms? How many oxygen atoms?

Write down all of the responses in "long hand" (e.g. 2 yellow + 3 green) first. Then go back and "abbreviate" each step along the way so they can follow the "train of thought" of you can get to subscript form. This is the shorthand way chemists use to describe chemicals/compounds/chemical formulae/combining ratios.

Students usually ask if double and triple bonds/connections between atoms allowed. The answer is yes – just not quadruple bonds because it is physically/geometrically impossible to do so. If you have made your atoms so that they are "anatomically" correct, you can instruct the students to try to make a quadruple bond between two atoms having 4 electrons. They will find that they can physically make a triple bond, but then the two remaining electrons are at 180^o from each other making another bond between them impossible.

4. Are double and triple bonds/connections between atoms allowed? (Yes – just not quadruple bonds because it is physically/geometrically impossible to do so)

Now make another new chemical with three different types of atoms.

5. How many of each atom did you use? What sorts of compounds did you make?

6. Did anyone use the atoms that have 8 electrons? How? Was it possible? (No, they are already paired)
7. Why not? (all electrons are paired, so none want another partner!)
8. Are all of the paired electrons the same? (yes, they cannot hook up with another atom - unreactive) *[Helium only has 1 house/1 pair instead of 4 pairs]*

Ask students to unhook compounds and place them back into the bags for the next lesson.

Lesson 1: TAKE-HOME MESSAGES/BIG IDEAS:

- ❖ When all electrons are paired, the molecule is stable.
- ❖ Chemistry involves the outer layer of electrons only, called the valence electrons. The number of valence electrons is a chemical property.
- ❖ All electrons are exactly the same regardless of how they are represented in this model. The electrons are the same in charge (negative), but not in distance from the nucleus.
- ❖ Making new electron-electron pairings is what we call chemistry or a chemical reaction to become more stable.

LESSON 2: ORGANIZATION OF THE PERIODIC TABLE

Lesson 2 Concepts:

1. The periodic table is organized so elements are arranged in columns based on the number of electrons available for chemical reactions (only the outer or valence electrons are available to do chemistry). Therefore, the elements in any column have similar chemical behavior because they have the same number of **valence** electrons.
2. Electrons are added to the atoms (not the same atom, but atoms with increasing numbers of protons) in layers - each row of the periodic table representing a different layer. Elements in lower rows have more total electrons, but the same number of valence electrons as those above them in the column.
3. Elements in lower rows react faster than those above them in the column because the electrons are further away from the nucleus.

Teacher Preparation:

- 4 periodic table blocks (s, p, d, f) are laminated and hanging up in front of the classroom
- Chart paper and markers for KWL
- s- and p-block atoms are divided and in bags, one bag per group
- Questions for think-pair-share on chart paper or handout

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Suggested Pre-lesson Activities:

- Review previous lesson concepts
- Revisit KWL
- Discuss examples of "everyday" classification
- Explore how a calendar is organized
- Questions for think-pair-share on chart paper and posted

Small Groups: Hand out bags of atoms to student groups.

You have a bunch of data in hand – different atoms! Remember, you do not know what is inside each one. Chemists are only concerned with the valence electrons because they are the ones hat do chemistry.

You might have noticed the periodic table on the wall. This is just an organizing chart for the data you have in front of you - the atoms!

- Discuss in your groups how you might organize your data (atoms) on this organizing chart.

WAIT! only a part of the Periodic Table is needed for this task.
So let's remove the parts we are going to ignore [f and d blocks for a start].
RIPPPPPP!!! Now move the p-block over so that it is next to the s-block – 8 squares across (see figure 1).

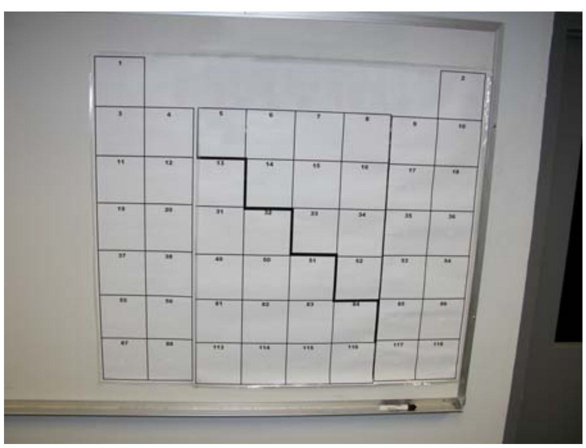

Figure 1: Periodic Table s- and p-blocks with d- and f-blocks removed.

These atoms fit onto the parts of the periodic table on the wall in front of the room. Your job is to organize the atoms so that they fit into the boxes of the periodic table. Discuss with your group what you are going to use as the basis of the organization? How will you do it? Talk among yourselves for a couple of minutes about how you might organize your data.

Now, come place your atoms on the periodic table as your group chose to organize them (use the Velcro on the atoms to stick to the Velcro on the table).

Note misconceptions:
Students may confuse atomic number with numbers of valence electrons. Tell students that all boxes of the periodic table need to have data in them, and there will be extra atoms left over.

To see what the periodic table looks like when the data is sorted correctly, see Figure 2.

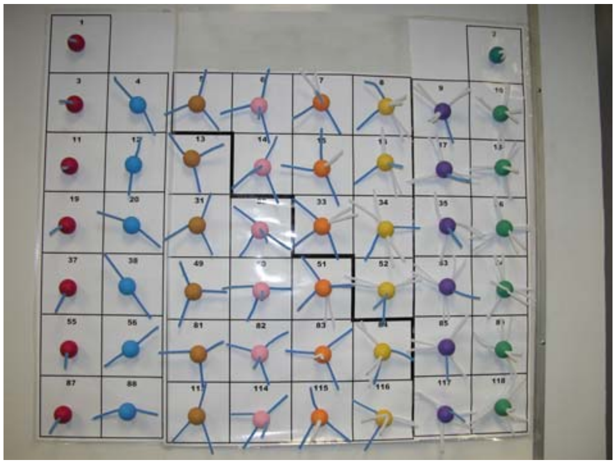

Figure 2: Atoms placed correctly on the s- and p-blocks of the Periodic Table.

Leading questions/hints to ask students to if they fail to appropriately organize the data:

- Do you see a repeating pattern?
- Every box needs to be filled.
- Does it look organized?
- How many rows do I have?
- How many columns do I have?
- How many different types of atoms do I have?

Whole group: Sample questions to students:

1. Did you all agree with the placement?
2. Compare/Contrast the basis of each groups' placement.
3. Can you think of other ways of organization that would make more sense?
4. Is one way of organization better than the other?
5. Is there a correct or incorrect way of organizing your atoms?
6. What would you like to change?

Ask students to come on up and make changes (see figure 2):

1. How did you decide how to organize the data this way?
2. What do you notice about the organization of the atoms? Or, what similarities do you see in each column? (atoms in each column are all the same color and have the same number of valence electrons)
3. What can you predict about the properties of each column? (same # of valence electrons, so each column has similar chemistry)
4. Do you see any trends? (increasing number of valence electrons across the chart, and repeats in the next row)
5. What does this remind you of? (a calendar) – what do you watch on T.V. every Sunday at 8pm?…every Monday? …this is periodic behavior.
6. If there is an increasing number of electrons as you move across the table, what do you know about the number of protons as you move across each period? (increasing number of protons which determine the identity of each element)
7. Are there other possible arrangements that might make sense? (yes - for instance atoms could be arranged 8-1 valence electrons from left to right)
8. How do you think you could decide which might be the correct one? (perhaps the numbers in the boxes provide a clue?)
9. What sorts of information might you need in order to decide?
10. Do you think that these atoms are placed correctly? What do you base your opinion upon?
11. Can you predict the general size of the atoms? (increase as you go down each column due to increasing onion layer, decrease across the column due to pull of more protons present)

Remember, you do not know what is inside the model atoms, and that the valence (outside) electrons are responsible for the chemistry.

1. What do the atoms in any given column have in common? What does this mean? (all have the same number of valence electrons. Without knowing how many electrons are in the "center" of the atoms, we do not know which one it actually is. In reality, it is easy to tell them apart because they have different masses and total number of electrons)

2. **If the electrons are responsible for the chemistry, which electrons do you think are the ones doing the chemistry**? (valence - and only those that are unpaired)
3. **So, what can you say about the chemistry of the atoms in any given column? Give a reason for this conclusion.** (If only valence electrons are responsible for the chemistry, their chemical behavior should be similar. Be sure to point out that chemical behavior refers to combining ratios. For further information about the data Mendeleev had to work with while developing the periodic table during the 1860s, see for example, Gordin (5).)
4. **What are the differences between the atoms in a column?** (different total number of electrons)
5. **What happens to atoms as you move down through the column?** (atoms get bigger because more "onion layers" are added). **Anything else? Why might atoms react faster**? (atoms in lower rows have more total electrons, more protons and more neutrons. They will react faster because the electrons are further from the nucleus and more likely to be attracted to an external partner. Additionally, the core electrons shield the valence electrons from some of the nuclear charge. An analogy: think about your "unfocused" students. Would you rather have them sit up front close to you or at the back of the room? Why? Another analogy: If you are sitting in the back of a room during a meeting, aren't you more likely to get distracted and possibly work on something else than if you are sitting right in front of the speaker? An analogy for students: students sitting in the back row are more likely to goof-off.

Student Journal Question:
"What are the different ways chemists read data on the periodic chart?"

- Across a row
- Down the column
- Linear as in the atomic number
- The staircase which divides metals from non-metals

Another journal option: Students journal trends in the organization of the periodic table.

You can even make predictions! Examine the combining ratios between the atoms of various columns. (Here is where mathematics comes into play! Look for least common denominators!)

Lesson 2: TAKE-HOME MESSAGES/BIG IDEAS:

- Periodic behavior: Moving across the periodic table, each row or layer begins with one valence electron until all the houses are filled with paired electrons starting again a new layer. With each new layer the outer electrons move further away from the nucleus.
- In each new layer (row), the outer electrons are further away from the nucleus.
- When all electrons are paired, the atom is "stable."
- Repeating pattern as you go across = **periodic behavior**
- Similar chemical behavior in a column or **family**
  (valence electrons do chemistry – builds on take-home idea from lesson 1)

Note that these ideas are built upon the big ideas from the previous lesson. You may wish to review those big ideas here.

LESSON 3: BONDING

Lesson 3 Concepts:

1. Periodic table can be used to make predictions about chemical reactions (e.g. combining ratios to make compounds).
2. Periodic table can be used to make some predictions about chemical compounds (e.g. column 1 + column 7 make a 1:1 salt).
3. Chemical compounds including covalent, polar, and ionic bonds.

Teacher Preparation:

- s- and p-block of large periodic table should be up and filled with atoms for s- and p-blocks where all atoms in a column have the same number of valence electrons.
- Bags of atoms
- Chart paper and markers for KWL
- Questions for students on chart paper or handout

ENGAGE, EXPLORE, EXPLAIN!

Suggested Pre-lesson Activities:

- Review previous lesson concepts
- Revisit KWL
- Go over organizational patterns of periodic chart. Students can share in groups journal entries. Whip around the room for any additional trends not mentioned previously, and add to chart.

We can made predictions about chemical behavior of atoms by examining their placement on the periodic table. Let's go back and examine the combining ratios of atoms from different columns. (This was already done when the students made binary compounds with the atoms before they placed the atoms on the periodic table. Bring out the charting of binary compounds that you made in lesson 1)

What would you expect the atomic rations to be in binary compounds formed from:

Binary Compound ratios:

Column 1 (alkali metals) with column 7 (halogens)	1:1
Column 1 (alkali metals) with column 6 (oxygen family)	2:1
Column 2 (alkali Earth metals) with column 6 (oxygen family)	1:1
Column 3 (boron family) with column 5 (nitrogen family)	1:1

Small Groups: Distribute bags of atoms.

Have students make some of the binary compounds. Relate these combining ratios to the chart from lesson 1. Sample questions to ask students:

1. Can you find a binary compound combining ratio that is 2:3 or 3:4?
2. Which are involved? (N family with O family; C family and B or C family)

Covalent, Polar, and Ionic Bonding:

1. If the atoms in the right hand column *(column 8)* do not do any chemistry, what does this tell you about atoms that have nothing but paired electrons? (They are stable – all atoms want to look like a noble gas. If possible, shared electrons count)

So, in order to be "stable," all atoms need to have the same electron configuration as noble gases. Atoms can do this in one of two ways. They can gain or lose electrons to become ions (atoms that do not have the same number of protons and electrons), or they can share electrons wit other atoms so that all available orbitals (electron houses) have two electrons. TEACHER INTERACTS with the atoms (by demonstrating ion formation - chenille stems are easy to pull out of or add to the Styrofoam balls) on the large Periodic Table as students answer the following questions:

2. If we were able to add or subtract electrons *to or* from *other* atoms, do you think the atoms in the *left* hand column *(column 1)* would rather take in more or lose what they have? (lose the one they have to become a positive ion. Alternatively, they could gain 7 electrons, but it would require too much energy to do so. The general rule is that making fewer changes require less energy and is therefore more likely. An example is $Na \rightarrow Na^+ + e^-$)
3. Why? (because then they would have the same number of electrons as the noble gases)
4. How about the atoms in *column 7*? (They would take in one electron to make a negative ion. Alternatively, they could lose 7 electrons. Taking in an electron requires fewer changes and is thus more likely. An example is $Cl + e^- \rightarrow Cl^-$. Point out to students that electrons do not just vanish or appear. The loss and gain of electrons occur in pairs of reactions)
5. Why? (because then they would have the same number of electrons as a noble gas)
6. So, which atoms do you think might want electrons more than others? Is there a trend? (atoms on the right side of the periodic table "hog" the electrons more because they get closer to having the stable arrangement of electrons that the noble gases have, while the atoms on the left side of the periodic table are fairly likely to give up their electrons so that they too attain the same stable electron arrangement that the noble gases have)
7. In a compound, the atoms from which column would share electrons most unevenly? (those with atoms from column 1 and those from column 7. These are termed **ionic** compounds - compounds where the electron actually defects from the column 1 atom to the column 7 atom)

8. Which atoms share the electrons exactly ***equally***? (two identical types of atoms like Cl-Cl. These are **covalent** bonds where the electrons are shared equally – *only occurs between 2 of the same element*)
9. What happens when the atoms share the electrons unevenly, but there is not a complete defection from one atom to another? (a **polar** bond results - uneven sharing, but not a complete defection to form ions)

Let's explore these three types of bonding (ionic, covalent, polar) and the results in more detail. TEACHER INTERACTS and models the following process using atoms on the large Periodic Table:

Covalent Bonding:

- When two identical atoms form chemical bonds, neither is "hogging" or "pulling" on the shared electrons more than the other.
- The result is that the shared electrons are shared exactly equally.

Ionic Bonding:

- Model with atoms (remove the electron from the atom that has only one electron and add it to the atom that already has 7 electrons): When Na combines with Cl, the electron from Na is removed and added to an unpaired electron on Cl to form an electron pair.
- The defection of the electron from one atom to the other changes the charges on both atoms. Remember that Na has 11 positively charged protons, but now has only 10 negatively charged electrons resulting in a net charge of +1; Cl, on the other hand, has 17 positively charged protons and now has 18 negatively charged electrons resulting in a net charge of -1.
- Properties of ionic compounds: Na^+Cl^- crystalline structure is due to the repeating pattern of attraction between (+) and (-) charges from all 4 sides, therefore ionic bonds are very strong.
- Bonding of metal + nonmetal

Polar Bonds:

1. What do you suppose happens when the electrons are not shared exactly equally, but do not completely defect to another atom? (shared unequally)

When electrons form a bond where the electrons are shared unequally, this is referred to as a polar bond. The atom that is more likely to hog electrons (e.g. O in CO) has a "partial" charge. A partial charge results from the shared electrons spending more time around one atom involved in a bond than the other.

Water is a molecule with polar bonds.

2. Which atom of water do you think is more likely to hog electrons? (oxygen)
3. So, do the electrons in each bond spend more time around the H or the O? (O)
4. Which atom(s) in water have a partial negative charge? (O)
5. Which atom(s) in water have a partial positive charge? (H)

Make a model of water (H_2O) and show it to students.

In addition, the oxygen in water has two lone pairs of electrons. The result is that there is much more negative charge around the oxygen atom in water making the molecule itself polar (but it is not ionic!). this means that water acts like a magnet with the more negative "oxygen end" being attracted to positive ions and positive sides of other polar molecules, and the more positive "hydrogen end" being attracted to negative ions and the negative sides of other polar molecules.

Interactions of Salts with Water:

Salts are compounds with ionic bonds. NaCl is table salt. Let's examine what happens when NaCl dissolves in water:

1. Which atom is positively charged? (Na)
2. Which atom is negatively charged? (Cl)
3. Which end of water is negatively charged? (O)
4. Which end of water is positively charged? (H)

TEACHER MODELS: collect the remaining group 1 atoms and group 7 atoms to make a salt crystal. Then demonstrate using your water molecule model that the oxygen end of water begins to solvate a Na (it takes a minimum of 4 water molecules to completely solvate either a Na or Cl and cart them off into the bulk liquid), while the hydrogen end of water will approach and begin to solvate a Cl. Once the ions are surrounded by at least 4 water molecules and distributed in the bulk liquid, the salt has dissolved. The fact that there are ions in solution results in two other properties of NaCl – one is that it tastes salty, the other is that the solution can carry a current (moving charges are a current – it is not just electrons that can do this).

The polarity of water molecules help to dissolve NaCl. The negative charge on the oxygen end of water attracts Na, and the positive charge on the hydrogen end of water attract Cl. Each water molecule acts as a "thug" and surrounds each atom of salt to dissolve. A web animation is available at http://www.mhhe.com/physsci/chemistry/essentialchemistry/flash/molvie1.swf

The fact that there are ions in solution results in two other properties of NaCl: one is that it tastes salty, and the other is that the solution can carry a current (moving charges are a current – it is not just electrons that can do this).

Lesson 3: TAKE-HOME MESSAGES/BIG IDEAS:

- Combinations of metals with a non-metal make an ionic compound. The periodic table can be used to make predictions of which molecules and compounds will have ionic bonds.
- A salt is a compound that when dissolved in water forms ions. These ions in solution carry electricity and tastes "salty." However, not all ionic compounds dissolve in water.
- Combinations between atoms in columns 1 & 7 make ionic compounds that are salts. There is a complete defection of the electron from the atom in column 1 to the atom in column 7.
- Combinations between atoms in column 2 & column 7 make ionic compounds that could be a salt; not all combinations of column 2 & column 7 will dissolve in water. Remember, to be a salt, they must dissolve in water.
- Smaller number of changes require less energy, therefore ions with lower charges are more common (e.g. NaCl)
- Atoms on the right side of the periodic table "hog" the electrons more because they get closer to having the stable arrangement of electrons that the noble gases have, while the atoms on the left side of the periodic table are fairly likely to give up their electrons so that they too gain the same stable electron arrangement that the noble gases have.
- Atoms want to look like a noble gas to be stable whether they gain or lose electrons

LESSON 4: PROPERITES OF METALS

Lesson 4 Concept:

1. Metals have a special set of properties because they share their electrons differently (communal sharing of electrons) than other materials, including salts.
2. Transition metals are organized on the periodic table in a similar way as the main group elements (as are f-block metals).
3. The meaning of malleable and ductile.

Pre-lesson Preparation:

- Add the d-block (10 across) and f-block (14 across) portion to the large Periodic Table.
- Place a variety of metallic styrofoam balls (columns 3-12) into bags and pass out to student groups.
- Variety of metals available
- Circuits to test conductivity

- Chart paper and markers for KWL
- Questions for students on chart paper or handout

ENGAGE, EXPLORE, EXPLAIN, EXTEND, EVALUATE!

Suggested Pre-lesson Activities:

- Review previous lessons: organization of s- and p-blocks, types of bonding.
- Revisit KWL
- Explore and discuss physical properties of metals

Small Groups:

Pass out transition-metal balls (the ones with 3-12 electrons and metallic colored). This procedure is similar to Lesson 1 in which students were asked to organized s- and p- block atoms on the large Periodic Table.

The new atoms you have in front of you belong on the part of the Periodic Table that I've just added.
Discuss in your groups how to organize this new data….
Come place your atoms on the newly added portion of the periodic table.

Figure 3 illustrates what the periodic table looks like when the atoms are sorted and placed correctly.

Figure 3: Periodic Table with all of the atoms.

Sample questions to ask students:

1. Do you all agree with the placement of the data?
2. Does the data look organized to you?

If not, come up and make changes.

3. How did you decide on the organization?
4. What do you notice about the organization of the data? (3 through 12 across the d-block. These atoms begin with 3 electrons because they are placed after the s-block)
5. How many electron "houses" do these atoms have? (6) How do you know? (12 total electrons, first pair of electrons appears for atoms with 7 electrons)

All of these new atoms are metals.

6. In what ways are metals different from other materials? (They conduct electricity, they have metallic luster, they are ductile, and they are malleable)

The reason metals have these special properties is that they share their electrons communally, instead of having electrons in localized bonds between atoms. (See below for a kinesthetic demonstration of metal properties)

People Movers Activity:

A "dance" in three parts:

1) **Demonstration of ductility** - this is the ability to draw materials (metals) through a small hole to make a wire. You will need to make an "orifice" through which you will "draw" the students. You can do this by laying down tape so that students can only pass through in single file. Line up the students in rows and columns to simulate a metal crystal. Ask them to "touch" those around them, but they will be free to move when they are "pushed" or "pulled" by you as long as they maintain touch. Explain that they cannot pass through a solid wall and must stay in the "open space" of the orifice you have laid out. Take one student by the hand and "pull" them through the "orifice". Since the other students need to maintain "touch" contact, this will eventually draw all students through the "orifice" in single file as if they were a wire.

2) **Demonstration of malleability** - Do this "dance" against a "wall" or place tape on the ground and explain that this is a wall through which they cannot pass. Then arrange students in rows and columns. Now hold a large circle (paper, Frisbee, etc.) and explain that you are the hammer that is going to pound on them - the piece of metal. As you gently "push" at some part of the metallic crystal, the students should move out of the way by spreading out against the "wall", while maintaining touch contact. Since they cannot go through the wall, all they can do is "spread". A material that can change its shape upon pounding without breaking is malleable.

3) **How are salt crystals different from metals?** "Reset" your crystal of rows and columns of students. This time the bonding is different. The students in every other row places their hands on the students in front of and behind them while the other students place their hands on the students beside them in both direction. Now, they are not allowed to "let go" of those they are touching. What happens as you try to "hammer" them? The only thing that can happen is that the crystal (if it reacts at all) it to cleave or shatter.

Metals communally share their electrons (unlike ionic or molecular substances). This different way of sharing electrons is responsible for the special physical properties of metals: malleability, ductility, conductivity, and luster. In other materials, electrons are shared between specific atoms in localized bonds or "monogamous" pairs. It is these localized bonds that result in the fracturing or shattering of the material when an attempt is made to change its shape without melting the material first.

EXTEND AGAIN!

There is still another part of the Periodic Table!

Now add the f-block (14 across) to the bottom of your periodic table. Sample questions to ask students:

1. What do you suppose the pattern is here? (14 squares across; starts with 3 electrons goes through 16 electrons; 8 electron houses (called orbitals))
2. What belongs in each box? (This is done without the benefit of actual atomic models to place on the periodic table).
3. So, what is the organizing principle for this portion of the periodic table? (8 electron houses/orbitals, 3 through 16 valence electrons, all atoms in each column are the same)

Lesson 4: TAKE-HOME MESSAGES/BIG IDEAS:

- Metal to metal bonds are where the electrons are shared communally because of this metals have special *physical* properties of ductility, malleability, magnetism, thermal conductivity, and electrical conductivity.
- Metallic bonding is much more communal – all electrons shared across all of the atoms, whereas the bonding between non-metals usually results in covalent (equally shared electrons) bonds, and ionic (electrons completely defect to the atom further to the right hand side of the periodic table) bonds between non-metals and metals. These bonds indicate that electrons form "monogamous" pairs.
- Atoms in the d-block and f-block of the periodic table are also organized according to the number of valence electrons each has.
- Elements having the same number of valence electrons and the same number of electron houses (orbitals) are organized on the periodic table so that they appear in the same column.

Final Assessment: A culminating exercise (either then or later):

Materials:

- Student periodic tables (one for each small group)
- Bag of buttons for each small group (each bag should contain a large variety of buttons)

Small Groups:
Have students place their illustrated periodic tables on their desk (one per group). Provide each group with a bag containing a variety of buttons. Ask the students to use the buttons to represent something they know about the data represented on the periodic table by placing buttons on your periodic table. This is a small group project. This assessment may be modified to accommodate different student ability levels. For example, lower level learners may be instructed to represent a limited number of trends on the periodic table at first, whereas higher level learners may be instructed to do so without any limitations.

Debrief:
Have the groups do a museum walk to see what other groups have done. Sample questions to ask students:

1. What do you notice about how another group chose to place their buttons?
2. What were they representing?
3. Did any group have something they represented that has not been pointed out? (Everyone go on over and see if you can spot it!)

TAKE-HOME MESSAGE/BIG IDEA:

Periodic chart organizes the elements in a variety of ways. Chemists use the chart to make predictions about chemical reactions.

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